EXECUTIVE SUMMARY

INTRODUCTION

One of the most obvious and practically sustainable methods of limiting the generation of poor quality leachate from sources such as coal discard dumps, waste dumps and opencast mine spoil, is by the provision of natural soil covers to limit the rate of infiltration, and by ensuring the optimum slope so as to attain maximum downslope discharge.

Soil covers are not entirely impermeable. Even after compaction some infiltration will inevitably take place. Covers can therefore never be designed to prevent infiltration entirely. The purpose of the cover is therefore to reduce the waste load generated to an acceptable level.

The efficiency of a soil cover depends on a number of factors of which the meteorological conditions are probably the most important. Evaporation should exceed rainfall by a significant margin where soil covers are used. Also the duration and intensity with which rainfall occurs determines the cover efficiency.

The type of soil used, its pre-conditioning and thickness are all important factors which must be considered in the design of soil covers. As the availability of different soil types is often a practical problem, manipulation of the available materials might result in better soil cover performance.

There is an urgent need to understand the behaviour and to assess the effectiveness of soil covers designed to control the rate of leaching of pollutants from discard dumps and waste piles. Adequate field data does not exist from instrumented large-scale experiments to verify theoretical models that predict the movement of leachate under unsaturated conditions.

The behaviour of soil liners and cover change with time. The suitability of soil barriers should be judged in terms of their long-term properties rather than those prevailing immediately after construction. For this reason it is necessary that covers be monitored in situ for long after construction in order to understand their true behaviour.

Presently there is an inadequate knowledge and experience to allow the advantages, disadvantages and costs of various rehabilitation techniques to be compared. There is also little consensus amongst experts in the mining industry on design criteria or methodology for natural soil covers.

This research project was initiated to address some of these shortcomings alluded to above, by constructing a large scale experiment, and monitoring cover performance over the three years. This data has been used to develop recommendations for the future design of soil covers. Another aim of the project was to identify and evaluate computer models that could be used to predict cover performance.

LITERATURE SURVEY

An extensive literature survey was undertaken. The literature was found to report mainly on theoretical and small-scale experimental results. There is, on the other hand, a lack of well-documented large-scale experiments and virtually no long-term performance data could be found. Further, there is limited information available on the use of soil covers over coal waste. Most literature covered complex multi-layer covers.

The literature does however lead to some conclusions. These include:

- Simple, single layer covers are not as effective as complex multi-layer covers
- The use of natural soil covers for preventing oxygen or water infiltration, is not practical. It can however reduce the rate of acid formation
- Materials like compacted clay, cannot retain their properties for long periods, especially if extreme wetting and drying cycles are prevalent
- The advantage of using vegetation to increase moisture loss by evapotranspiration, is offset by the effects of soil break up and increased infiltration due to root ingress
- Cover performance varies. Outflows from the base of soil covers of between 1% and 60% of rainfall have been documented
- Compaction and moisture content control may reduce the permeability of soil covers.

PRINCIPLES OF UNSATURATED FLOW

Water movement through a soil cover and in the waste underneath generally occurs under unsaturated conditions. This implies that the pores in the soils and waste are partly filled with air. The presence of the air reduces the dimensions of the flow paths. Flow under unsaturated conditions is therefore considerably less than under saturated conditions. Flow dynamics in the unsaturated zone also controls diffusion and transport of oxygen from the surrounding air since a high moisture content in the cover material is required to restrict this transport.

EXPERIMENTAL SETUP

The experimental site for this project was constructed in 1993, at the Ngagane station, near the town of Newcastle in Kwa-Zulu Natal. The site comprised 10 test cells, simulating the cover configuration of coal discard dumps. The cells were designed with the following objectives in mind:

- The cells had to be of a large enough scale to be representative
- The boundary effects had to be known
- The experiment had to be instrumented to provide sufficient data
- Soil properties of the covers had to be known
- The effect of vegetation and slope had to be measurable.

The climatic conditions at the site are typical of that throughout South Africa, with summer rainfall, falling mostly in short high intensity thundershowers. The climatic data was logged electronically on site using a weather station. Hourly readings of rainfall, temperature, relative humidity and net radiation was measured.

Soils typically used as cover materials for discard dumps were selected. These materials as well as the coal discard were tested extensively, both in situ and in the laboratory, to determine physical and hydraulic properties.

Three of the 10 cells were uncovered, one being completely uncompacted and another completely compacted. The third uncovered cell was uncompacted but vegetated. Two simple single layer covers were used, in cells 4 and 5, the first a 300-mm-thick uncompacted Avalon (loam) soil cover, and the other a 500-mm-thick compacted Avalon soil layer.

Cells 6,7 and 8 had 1-m-thick layered covers, two with a combination of uncompacted Avalon and Estcourt (clay) soils and the other with a combination of compacted and uncompacted Avalon. Cells 9 and 10 were covered with Estcourt and Avalon combinations and were sloped at 5% and 10% respectively. All the cells, except two of the uncovered ones, were vegetated with grass.

The cells were designed to drain freely from the base of the coal discard. The volume of outflow was measured by means of tipping buckets. Oxygen and carbon dioxide levels were also measured in the top 150 mm of each coal layer immediately beneath the soil cover. These results give an indication as to the effectiveness of the covers as oxygen inhibitors.

Water samples were taken at regular intervals, to determine how the quality would change with time. Other factors that were monitored intermittently were the soil temperature, and the in-situ moisture content throughout the soil profile.

EXPERIMENTAL RESULTS

The coal particle density (SG) was found to be low. This is consistent with the high carbon content. No significant difference was found between SG for the Avalon and the Estcourt soils.

The coal discard had the lowest bulk density and the lowest porosity. The Estcourt had the highest bulk density and the lowest porosity of the two soils used. The porosity of the compacted coal discard and soils was found to be lower than for the uncompacted materials.

The water retention characteristics of the coal materials were found to be different from that of the Avalon and the Estcourt Soils. Insignificant differences in the retention characteristics were found between the compacted and uncompacted coal discard and Avalon soil. The Estcourt soil was found to have the steepest retention curve, confirming its greater water holding capacity.

The saturated hydraulic conductivity was determined using four different methods. Permeability was found to be one order of magnitude higher for the Avalon than for the Estcourt soils.

The leachate qualities recorded at each cell in the experiment are a function of the various geohydrological, geochemical and biological process associated with the coal discard material. A geochemical and statistical analyses of the leachate quality database revealed that the single-layered dump covers (cells 4 and 5) are less effective in preventing the production of acidity and salinity from the discard material. However, these single-layered dump covers, relative to the uncovered cells, managed to inhibit the oxidation of pyrite and was reflected in a lower increase in salinity with relative neutral pH levels. This means that an acid breakthrough in leachate quality will occur but will only take place in a number of years.

Multi-layered soil covers showed to have the capacity to create permanent anaerobic conditions, which not only inhibits the oxidation of pyrite but actually prevents it. This was reflected in a general improvement in leachate quality recorded at the multi-layered cells (cells 6-10) for most of the monitoring period.

The outflow results generally follow expected trends. As expected, the uncovered cells are the least effective in reducing the outflow, which averaged around 26% of precipitation. The compacted, uncovered cell performed slightly better than the uncompacted cells reducing the outflow to around 21%.

The single layer covers (cells 4 and 5) had an average outflow of 17% of precipitation. The uncompacted cover of cell 4 registered 5% more outflow than the compacted cover of cell 5.

The layered covers performed only slightly better with a combined outflow of around 15%, with the cells containing clay performing worse than the cell covered with only Avalon soil.

The sloped cells (9 and 10) were expected to have the least outflow, but ended up with outflows similar to the near horizontal cells at around 16%. On all the cells an increase in outflow was observed to coincide with the establishment of vegetation. We are however not convinced that this increase was due to the effect of foot penetration alone, grass was established during a period of abnormally high rainfall.

MODELLING

Numerous computer codes claim to model unsaturated flow. Forty-four (44) of these were identified and evaluated. Only 17 were found to simulate evapotranspiration. One was selected for calibration on the basis that it satisfied the minimum requirements and relatively inexperienced users would be able to operate it.

SWACROP is a transient one-dimensional finite difference model for simulation of the flow of water through the unsaturated zone. This model was used to compare the experimental data with theoretical results. The tool was found to have the capability of predicting cover performance to assist in the prediction of cover efficiency.

Modelling calibration proved to be unsuccessful. The model, in all circumstances, predicted significantly higher outflows than observed in the field. Reasons for these discrepancies were postulated to be the timestep and the spreading of all rainfall in any one day over the full day.

CONCLUSIONS

A soil cover of at least 300 mm over coal spoils was found to reduce the potential outflow by at least 50%, to be in the range of 17% of MAP. A further reduction of between 2% and 4% would have been gained by compacting the cover clayey material which is susceptible to desiccation cracking, should not be used. Outflow can be reduced further by reshaping to form steep slopes, which maximise runoff.

It would appear that the multiple layered covers do not perform better than the single-layered covers. The 500-mm compacted Avalon cover was found to outperform the multiple layered covers throughout the duration of the experiment.

Throughout this experiment the Avalon soils appeared to have more potential for reducing outflow than the Estcourt soils, this suggests that the Avalon's high water retention properties, coupled with its low susceptibility to desiccation cracking makes it the most suitable for cover material in semi-arid climates.